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MEAN CIRCULATION PATTERNS BASED ON 12 YEARS OF RECENT NORTHERN HEMISPHERIC DATA

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ABSTRACT

A new set of long-period means for sea level pressure and 700-mb. height, based on 12 recent years of reliable upper-level and surface observations in the Northern Hemisphere, is constructed. Comparison with the normals currently in use, which are based on data prior to 1950, reveals additional information and some significant differences, principally at high and low latitudes. The three cells of the polar vortex at 700 mb. are not as deep as shown in the normals, the cells over Baffin Island and the Siberian Arctic are farther north, and the Kamchatka cell is found primarily over the Bering Sea rather than over land. The Pacific High at 700 mb. is tricellular on an annual basis, with the additional Philippine cell becoming the dominant cell in late winter. Other new features in the 700-mb. means include troughs near Spitzbergen, Alaska, the Philippine Sea, and the Bay of Bengal; and Highs in northeastern Siberia and the Caspian Sea area. Patterns of height differences between the new means and the normals suggest that a long-period trend toward increased blocking has been in progress during the last decade, particularly in the Baffin Bay area.

1. INTRODUCTION

In the preparation of a study of the frequencies of 5-day mean 700-mb. Highs and Lows for the years 1947–1958 (to be published), it was noted that there was poorer correspondence than might be expected between some areas of maximum frequency and the long-period mean circulation pattern in the Northern Hemisphere currently in use as a normal; i.e., the normals published in 1952 [1] and based on data prior to 1950. In January, for example, the frequencies showed a secondary maximum of mean Lows near the Denmark Strait and a clustering of Highs over Greenland, features not adequately reflected (by vorticity maxima) in the 1952 normals. Similar discrepancies could be noted by comparison of the 1952 normals with the frequencies of 5-day mean 700-mb. troughs and ridges during the period 1947–1955 published by Klein and Winston [2].

It might be argued that any disparity between the frequencies and normals may be due to a different circu-

lation regime in the 12 years embraced by the frequency studies (1947 and later years) than in the earlier period prior to 1950 embraced by the normals. To the extent that this is true, then, the earlier normals no longer adequately reflect current modes of synoptic behavior, so that it might be desirable to adopt a more up-to-date set of normals which more accurately represent current trends. (In this connection, it might be noted that the Weather Bureau following the World Meteorological Organization *Technical Regulations* [3] adopted the policy of revising 30-year surface temperature normals once every 10 years by adding data of the most recent decade and dropping the earliest decade.)

As a result of the above considerations, a new set of long-period means for the years 1947–1958 was prepared. This was the longest continuous period of relatively accurate hemispheric analyses for 700 mb. available on punched cards in the files of Extended Forecast Section, and it embraced the same period as used in the frequency study of mean Highs and Lows. Subject to the reserva-

tions discussed later, the 12-year means presented here probably reflect as accurate a portrayal of the long-period circulation as could be obtained.

The principal charts to be presented consist of four sets, as follows: (a) 12 monthly 700-mb. means; (b) 12 charts showing the differences between the 700-mb. 12-year means, by months, and their 1952 normal counterparts; (c) 12 monthly sea level means; and (d) 12 charts showing the differences between the 12-year mean 1000–700-mb. thicknesses by months (not shown) and their 1952 normal counterparts. Obviously these charts may be used, if desired, without any reference to the text, which points out in some detail the deficiencies of earlier data (section 2), composition of the 12-year means (section 3), differences in circulation features at 700 mb. (section 4), annual oscillation of the 12-year mean circulation features at 700 mb. (section 5), comparison of height differences at 700 mb. in relation to long-period changes (section 6), differences in the 700-mb. zonal indices (section 7), stability of the 700-mb. height differences (section 8), comparison of sea level patterns (section 9), comparison of thickness patterns (section 10), and conclusions (section 11).

2. DEFICIENCIES OF EARLIER DATA

The 1952 normals presented in [1] were a heterogeneous combination of different periods of data from different areas, and, especially for the upper levels, relied to a great extent on daily analyses arrived at indirectly. This is not surprising when one realizes that the history of direct upper-air measurements is short compared with that of surface observations. It was not until the end of the decade of the 1930's that radiosondes came into extensive use even in the United States, although some measurements were made from airplanes early in this period. Upper-air meteorology based on actual measured data, and of a scope even resembling a hemispheric basis, is thus barely 25 years old at this writing. Furthermore, because of the disruptions in data coverage at various times by wars, etc., only since the end of World War II has there been a relatively uninterrupted flow of data on a hemispheric basis on which a reliable long-period upper-air mean could be based. Over the oceans, for example, prior to near the end of World War II, synoptic upper-air observations from shipboard weather stations and regularly scheduled aerial weather reconnaissance observations were non-existent. Thus the oceanic circulations at upper levels were largely derived from surface observations prior to 1946.

It is well known, as pointed out by Namias [4], that prior to World War II, analyses over the Polar Basin were largely unreliable owing to lack of adequate observations, both surface and aloft. In fact, the analyses during the 1946–1950 period, on which the 1952 normals relied heavily in some areas [1], were still far from adequate in the polar regions, although there was an unprecedented increase in observations during that period. The same

deficiencies existed in other parts of the world, particularly in parts of Asia (e.g., China, where upper-air data did not become available until 1956), and at lower latitudes over both land and sea. For these reasons, short-period means based on recent observed data have been used in place of the normals by numerous authors, including Namias [5], Reed and Kunkel [6], Bryson, Lahey, Somervell, and Wahl [7], and Jacobs [8]. In no case however, has any previous mean been based on a continuous period of record even as long as 12 years.

In view of the heterogeneous combination of different periods of record and different methods of obtaining data used in the 1952 normals, it would be indeed surprising if differences could not be found between them and more recent long-period averages, especially considering the tremendously increased data coverage in the last decade or so. It will be observed that both the 1952 normals and the 12-year means presented in this paper contain four of the same years; i.e., 1947–1950. Therefore the comparisons presented here are essentially between features of the eight years 1951–1958, which probably contain the best observational basis in the history of upper-air meteorology, and features of a period of sparse data prior to 1946.

3. COMPOSITION OF THE 12-YEAR MEANS

Figures 1–12 portray the new monthly 12-year means at sea level and 700 mb., together with thickness and height departures from the 1952 normals.

These means were obtained by averaging, for each calendar month, the 12 monthly means for the years 1947–1958. Each monthly mean in turn represented an average of 60 synoptic analyses; i.e., 30 days of twice-daily data. Through the years each 12-hourly analysis has been placed on punched cards in the form of heights and pressures interpolated at standard intersections of latitude and longitude in the shape of a diamond grid. The intersections employed are those formed by latitudes and longitudes both of which are evenly divisible by 10, and also by those intersections both of which end in digit 5. For example, 40° N., 60° W. and 35° N., 55° W. are used, but not 35° N., 60° W., etc. The same grid was used in the preparation of the 1952 normals (see fig. 1 of [1]).

The punched card data fell short of providing a full 12-year average in some areas. Over much of Asia north of 40° N., only the months November and December are true 12-year averages, the other 10 months representing 11-year averages in this area. Over Africa east of 10° E. and Asia between 30° N., and 40° N., the patterns represent 10-year averages, and at 20° N. and 25° N. they represent only 8-year averages in this region. These averages, however, are the most recent years in all cases.

Although the punched-card data over China and Southeast Asia represent 10- to 12-year averages, actual daily observations during much of this period were

mostly absent, especially from China. Of course, this is almost always the case over some parts of the world, especially the oceans, even to the present day. Over these ocean areas vertical extrapolations from generally available surface data usually permit delineation of relatively reliable upper-air patterns, especially where the lapse rates are normally not excessively stable at low levels. These extrapolated values are then integrated with actual upper-air reports from ocean weather vessels and islands. However, over China the absence of surface as well as upper-air observations required dependence on horizontal space and time continuity only. It is therefore believed that the patterns presented here may be considered least reliable in the interior of Southeast Asia, but, interestingly enough they are not as different from earlier normals as they are in some other areas. This might be explained by the necessity of using the same techniques of extrapolation in both periods since data were largely absent for both.

The 1000–700-mb. thickness charts (not presented) from which the departures in figures 1D to 12D were computed, were prepared by converting the new mean sea level pressures at each grid-point into heights of the 1000-mb. surface by using a constant height equivalent of 26 feet for each millibar of departure from 1000 mb. This height equivalent is valid near 32° F. This results in varying degrees of error depending on both the extent to which average temperatures depart from 32° F., and the extent to which the mean pressures depart from 1000 mb. (see table 58 of [9]). Thus over the eastern portions of continents in winter north of about 50° N., where mean pressures are relatively high and temperatures may average as low as –50° F., the thicknesses computed by this method are less than actual thicknesses, and positive corrections might be needed locally (such as in the vicinity of Verkhoyansk, USSR, near 67° N., 133° E.) of perhaps as much as 100 feet in the months of January and February.

Similarly in the vicinity of the subtropical oceanic Highs in summer, negative corrections of perhaps as much as 50 feet have to be applied. Elsewhere the thickness difference patterns should be reasonably accurate since the magnitude of the error introduced by the above method diminishes as the mean pressure approaches 1000 mb.

4. DIFFERENCES IN CIRCULATION FEATURES AT 700 MB.

The principal features of the 12-year mean 700-mb. charts (figs. 1A–12A) will now be described and compared to corresponding features of the 1952 normals.

(1) Baffin Island Low

At 700 mb. this center is generally not as deep and is farther north on the 12-year means by as much as 7° of latitude in the winter months, as compared with the normal.

(2) Cyclonic Vorticity in the Denmark Strait

In the 12-year means this feature is present at 700 mb. from November to February, with a low center from June to October, but these features are not as pronounced in the normals.

(3) Atlantic Subtropical High

This High is slightly weaker on the 12-year means during most of the year, with the western cell centered east, instead of west, of Cuba in November and December. The trough between the two cells in the cold months is generally 7° or 8° east of the normal position. The westward extension of the Atlantic ridge becomes a separate High center in the southern United States in August, September, and October, a feature absent in the 1952 normals.

(4) Spitzbergen Trough

A short trough shows up in nearly all months at 700 mb. near Spitzbergen in the 12-year means, whereas the normal shows a ridge in this area in most months, notably February.

(5) North American East Coast Trough

This trough at 700 mb. appears farther east on the 12-year means in some months, notably October, while in other months, such as December, it is farther west.

(6) Alaskan Trough

A distinct trough or shearline appears in the new 12-year 700-mb. means during winter months over Alaska, in contrast to ridge conditions in the normals, notably in January and February.

(7) Pacific High

The 12-year means at 700 mb. reveal that the Pacific High is tricellular in the fall and winter months, bicellular in the spring, and single-celled and strongest in July. In August a weak central Pacific cell and a weaker Philippine cell become evident, with the central cell becoming predominant in the fall months. The central Pacific cell and the Philippine cell become equally dominant in December, while in the winter months the Philippine cell becomes the strongest cell in the Pacific High. In April and May the eastern cell disappears, reappearing strongly in June. Little of this detail is apparent from the 1952 normals.

(8) Hawaiian Trough

A distinct trough at 700 mb. occurs near the Hawaiian Islands from November to about March, separating the eastern and the central Pacific High cells. In March this trough appears to be associated with a Low south of the Islands. The proximity of this trough is closely related to the winter rainfall maximum in Hawaii, while the absence of a trough in summer is associated with relative dryness there.

(9) Philippine Sea Trough

From July to November a trough appears in the 12-year 700-mb. means just east of the Philippine Islands, separating the Philippine or South China Sea High from the

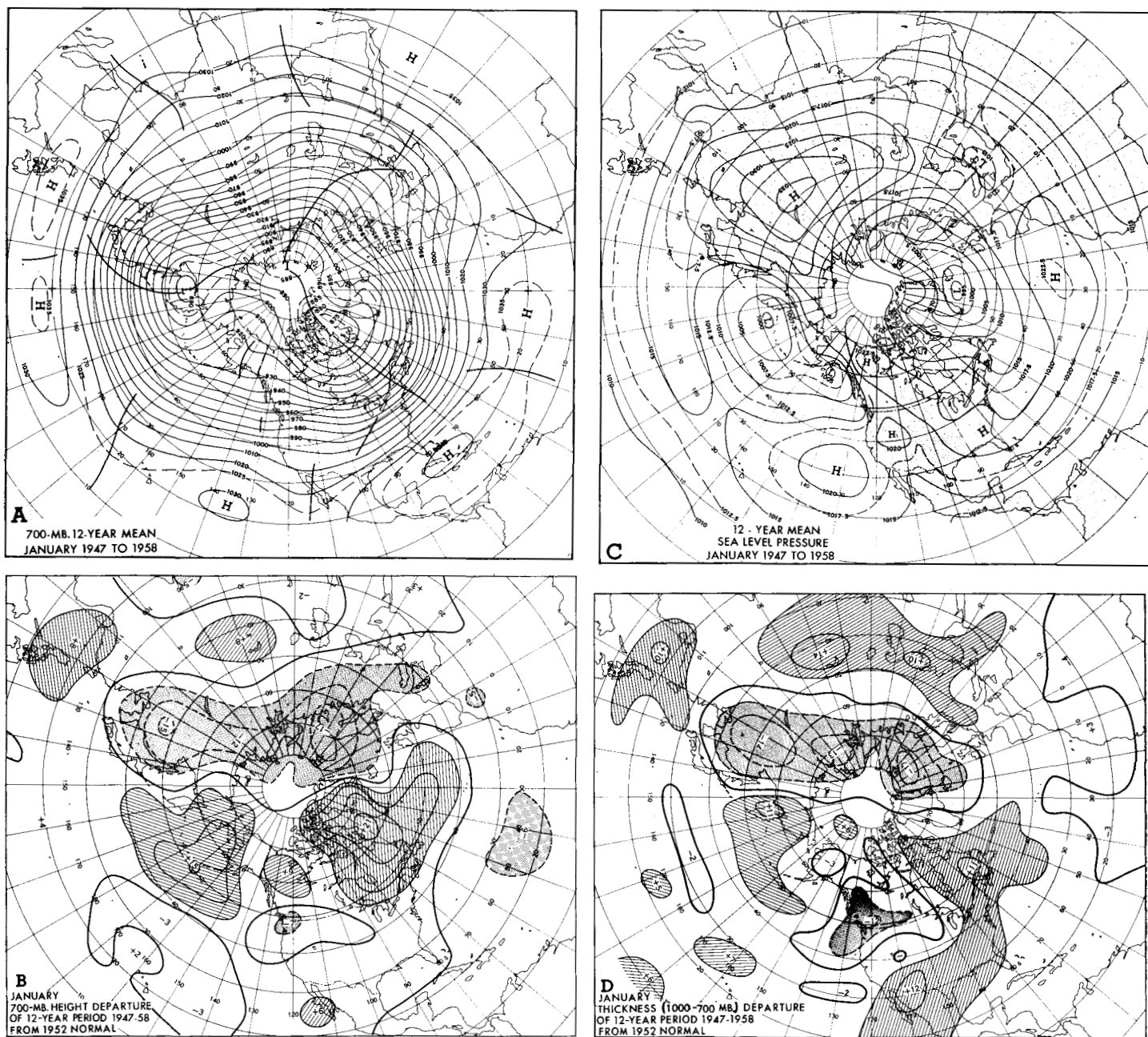


FIGURE 1:

A. 12-year average contours of the 700-mb. surface (tens of feet), drawn at intervals of 100 ft. with selected intermediate contours dashed. Trough lines (heavy solid) delineate the loci of height minima along adjacent latitude circles.

B. Height differences (tens of feet) between 12-year average 700-mb. heights (A charts) and corresponding 1952 normals [1]. Heavy solid lines indicate zero differences. Hatched areas have positive differences and stippled areas have negative differences of more than 50 ft. The lines are drawn at intervals of 50 ft. with positive differences solid and negative differences dashed.

C. 12-year average isobars of sea level pressure (millibars) drawn at intervals of 5 millibars with selected intermediate isobars dashed.

D. Differences between 12-year average thicknesses (1000–700 mb.) (tens of feet) and corresponding 1952 normal values [1]. Heavy solid line indicates zero differences. Hatched areas have positive differences and stippled areas have negative differences of more than 50 ft. The lines are drawn at intervals of 50 ft. with positive differences solid and negative differences dashed.

central Pacific cell. This trough probably reflects the locus of typhoon activity which reaches a maximum at this time of year.

(10) Kamchatka Low

In the winter months this Low at 700 mb. is farther

west and not so deep as shown in the 1952 normals. In July and October the vorticity maximum or Low is found over the Bering Sea rather than over adjacent Siberia as in the normal. In November this Low is found near the Kamchatka side of the Bering Sea, in contrast to the position in the normal nearer Alaska.

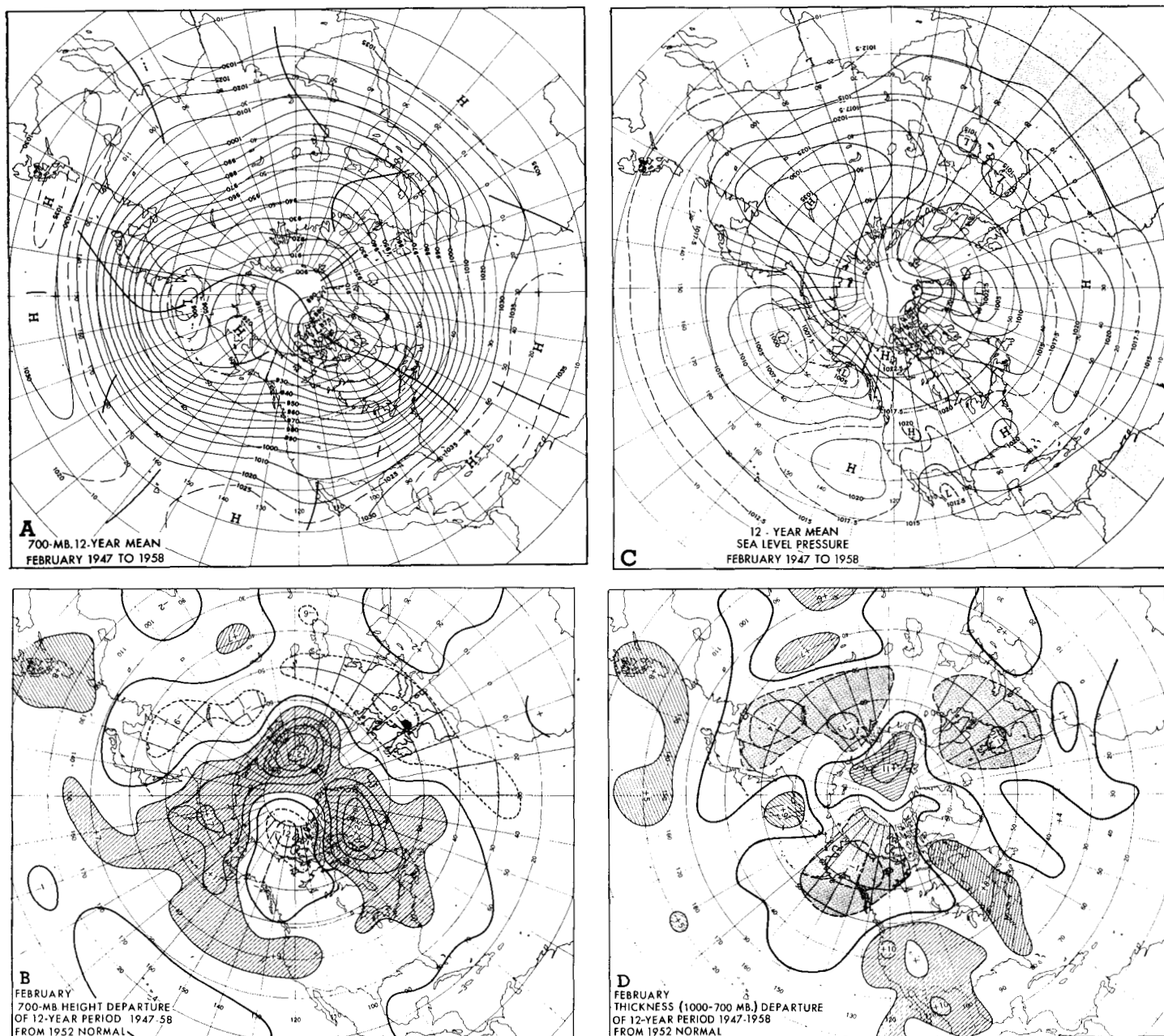


FIGURE 2.—(See legend to fig. 1.)

(11) Northeastern Siberian High Cell

A small High cell appears in extreme northeastern Siberia in the new 12-year means at 700 mb. in some of the colder months such as November, December, and February. This feature does not appear on the earlier normals. Its existence is associated not only with greater heights in this area than in the earlier normals, but also with the Alaskan trough which is also a new feature found in the 12-year means. This High cell is essentially a cut-off portion of the Yukon Ridge.

(12) Siberian Arctic Low

The 12-year means at 700 mb. show marked differences in the position and intensity of the second deepest cell of

the polar vortex, the Siberian Arctic Low. In January this Low is deeper than the Kamchatka Low, a reversal from the situation in the earlier normals, while in February this Low disappears as a circulation center, although it is still shown as such on the normal. In April it becomes the largest cell of the polar vortex, whereas the normal map shows only one deep center over Baffin Island. In June the Siberian cell becomes the deepest system in the Northern Hemisphere, and from July to September it apparently becomes the polar vortex, close to the North Pole on the Siberian side. In October and November this center is connected by a trough to the Baffin cell, whereas the normal shows a ridge separating the two. In December this center is found considerably farther

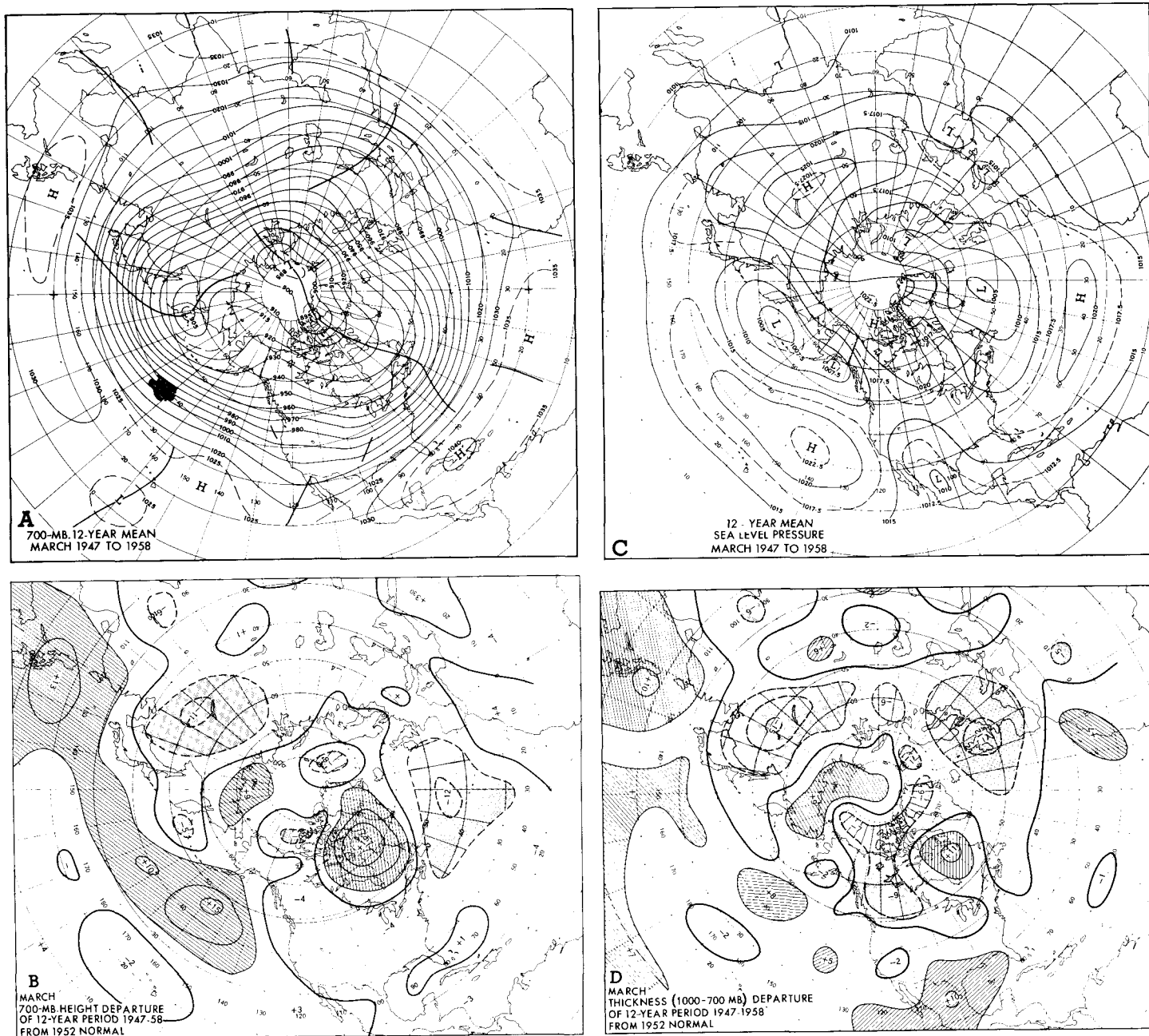


FIGURE 3.—(See legend to fig. 1.)

west near Spitzbergen, where a ridge is shown on the 1952 normals.

(13) Bay of Bengal Trough

In the new 700-mb. means a trough is found near the Bay of Bengal in all months, primarily over Burma in the first half-year, and near India in the summer. In contrast, the normals show this trough near the Philippines during some months, where the 12-year means show a High cell predominating from the fall to the end of spring.

(14) Caspian Sea High

In the summer months an anticyclone builds up at 700 mb. near the southern shore of the Caspian Sea,

reaching a maximum height in August. This feature is not evident from the normals.

(15) Russian Trough

A trough oscillates throughout the year about a mean position in western Russia, generally extending across the Black Sea into the eastern Mediterranean. This trough does not usually connect directly with the Siberian Arctic Low, since another persistent trough connects the latter across northeastern Siberia with the Kamchatka Low. In April and May there are marked differences from the normals in orientation and location of the Russian trough. In July this trough appears to be well developed southward along 40° E. longitude, where in

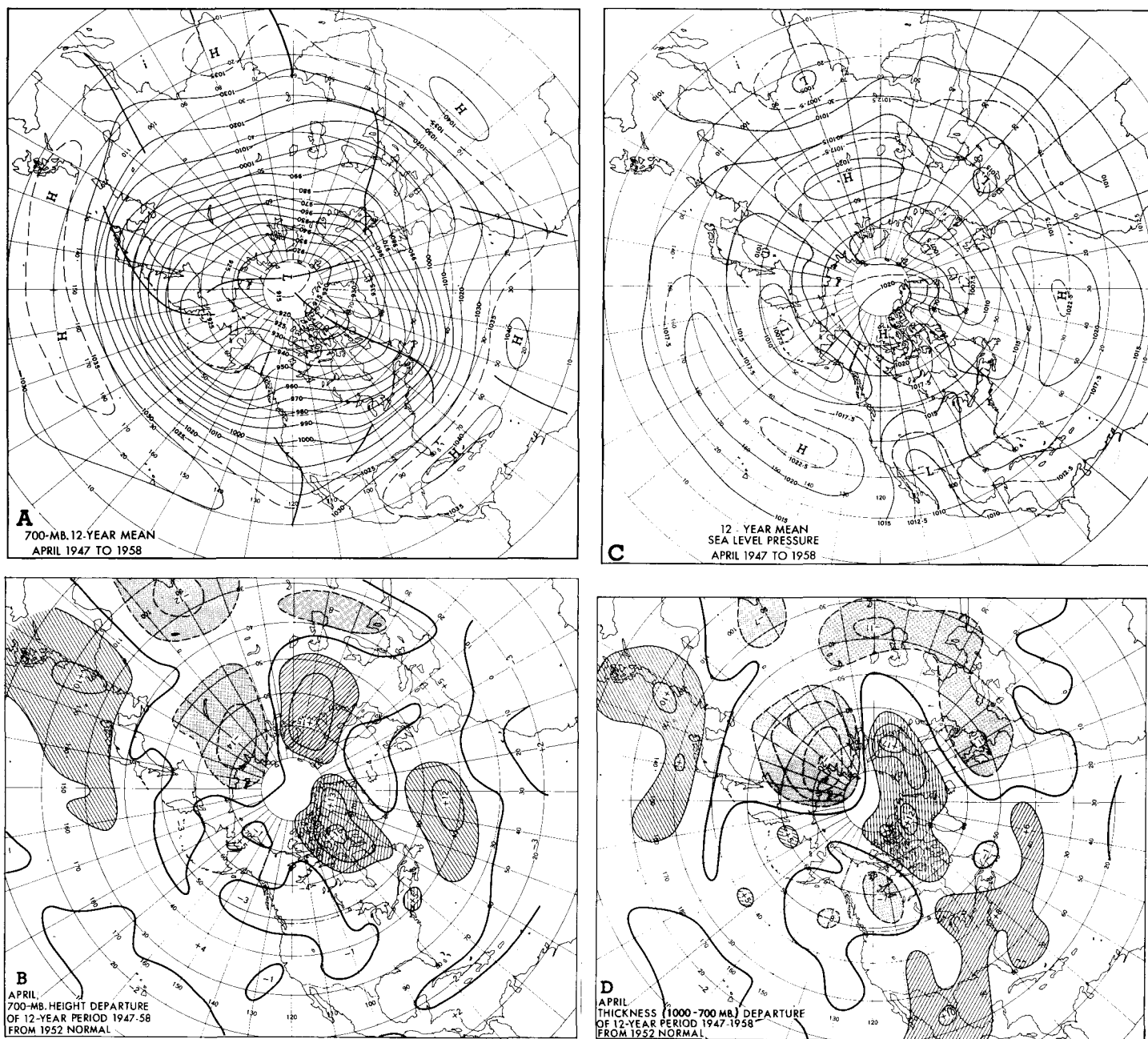


FIGURE 4.—(See legend to fig. 1.)

the 1952 normals, a ridge is located at higher latitudes. In July and August this trough is fairly strongly developed from the eastern Black Sea southward, while the normal indicates little or no trough there. In the winter months the southern position of the Russian trough snaps back westward to the Italian peninsula.

5. ANNUAL OSCILLATION OF THE 12-YEAR MEAN CIRCULATION FEATURES AT 700 MB.

Many of the mean circulation features at 700 mb. oscillate with considerable regularity according to the season. Some of the prominent oscillations are as follows:

(1) Alaskan Trough

This trough migrates eastward from the Bering Sea in the fall to its easternmost position in central Alaska in February, after which it disappears.

(2) Pacific Coastal Trough

This feature at 700 mb. oscillates within about 15° of longitude west of Lower California throughout the year. It elongates northward along the west coast of the United States during spring, reaching its northwesternmost position in late summer about 5° off the coast of the Pacific Northwest. Subsequently it retreats southeastward, reaching southern Arizona in December. The North African coastal trough behaves in almost precisely the same fashion.

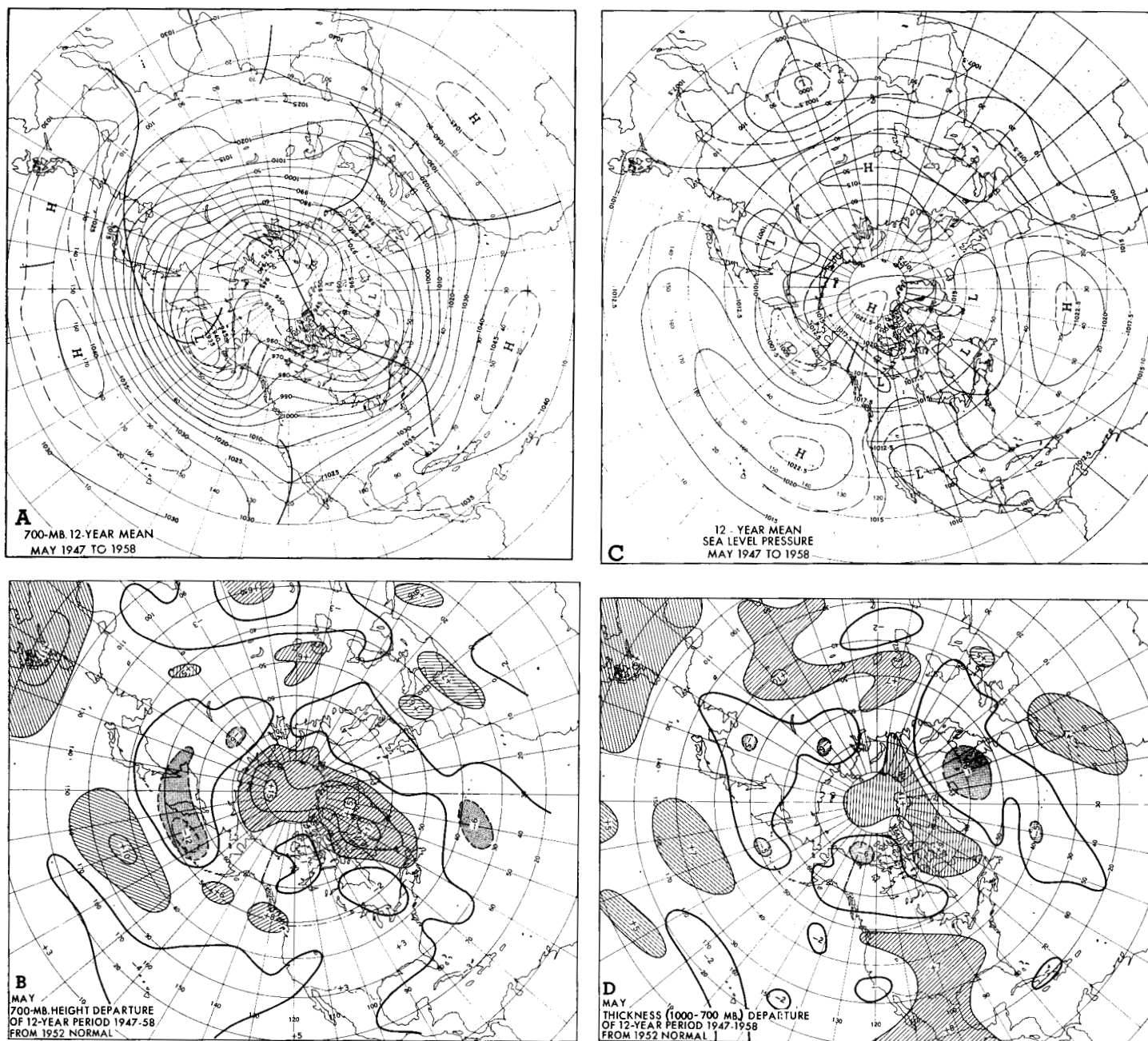


FIGURE 5.—(See legend to fig. 1.)

(3) Eastern Cell of Pacific High

This cell at 700 mb. migrates discontinuously northwestward about 25° of latitude from its southeasternmost position between Hawaii and Lower California in January and February to its northwesternmost position north of Hawaii at 35° N. in July and August, after which it returns to its southernmost position near year's end. This oscillation is similar to that of the west coast trough, but over a greater span of longitude.

(4) Central Pacific High Cell

This cell migrates northeastward at 700 mb. about 15° of latitude from its southwesternmost position in winter to its most northeastern position in late summer and early

fall. It retreats rapidly to its southernmost position after October.

(5) Philippine High Cell

This cell is very stable in position from January to May east of Luzon. It disappears in June, reforming as a weak cell in August and September over the southern Philippines. During the remainder of the year it is located north or west of the Philippines.

(6) Bengal Trough

In the first five months of the year this trough migrates eastward across Burma at 700 mb. It appears on the west side of the Bay of Bengal from June through October, in association with the Nepal or Indian Low. By year's

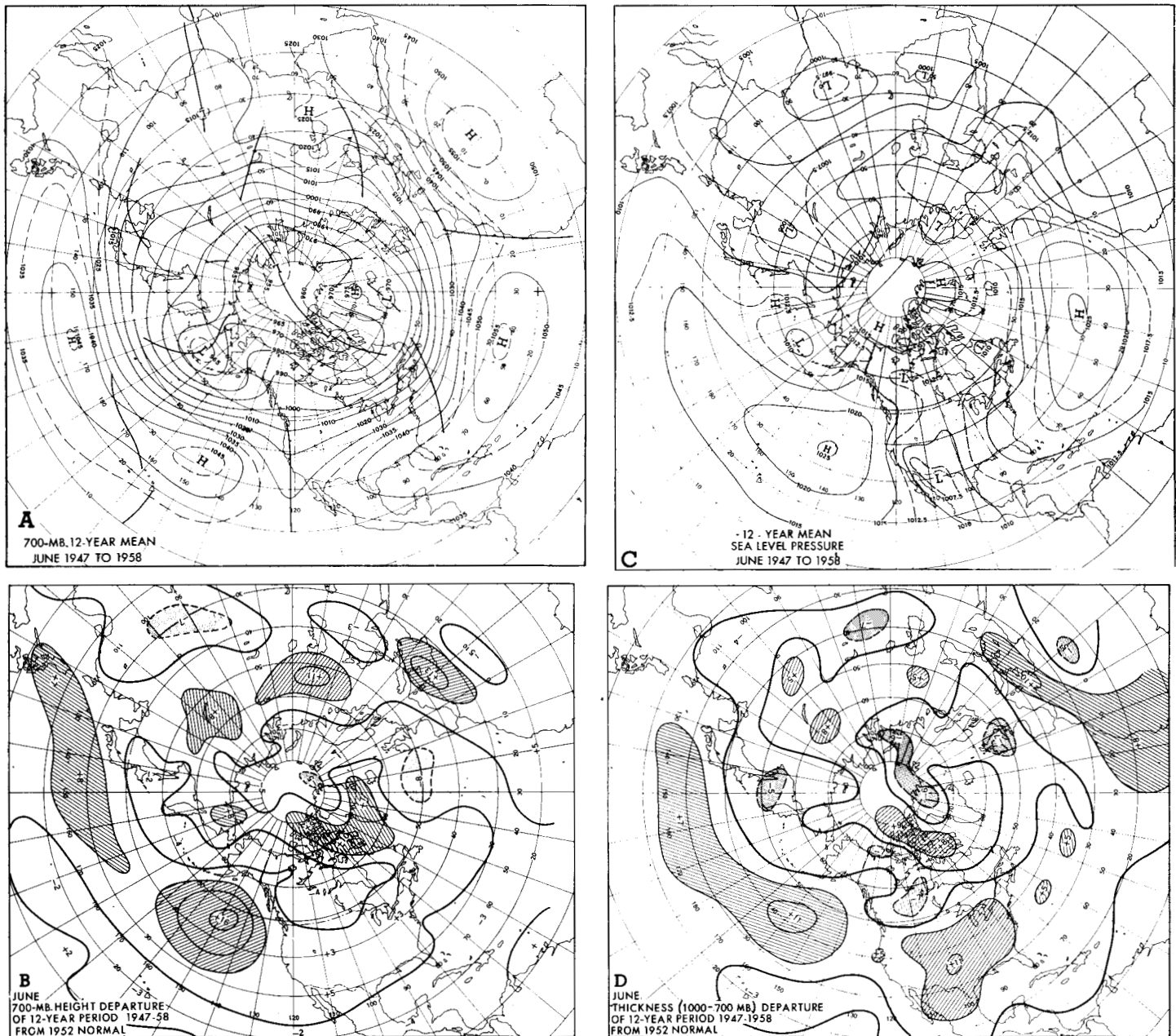


FIGURE 6.—(See legend to fig. 1.)

end it is located in the central Bay of Bengal, heading eastward toward Burma.

6. COMPARISON OF HEIGHT DIFFERENCES AT 700 MB. IN RELATION TO LONG-PERIOD CHANGES

Figures 1B to 12B show that there is a good correspondence, as reflected in smaller height differences at 700 mb., between the new 12-year averages and the earlier normals in some areas, such as the contiguous United States, where earlier data were fairly plentiful and relatively accurate. This might lead to the inference that the more substantial differences in other areas reflect earlier errors rather than long-period changes. However, this is not necessarily true in all areas, since the difference patterns frequently show

up as couplets of adjacent height difference patterns of opposite sign.

The existence of these couplets in certain areas and seasons suggests that departures of a certain sign in one area are dynamically linked with departures of opposite sign upstream or vice versa. For example, the negative differences in January at 700 mb. over Manchuria (fig. 1B) are associated with the positive departures of similar magnitude in the north-central Pacific probably through barotropic propagation of vorticity. In other words, if the negative differences over Manchuria merely represent a compensation for erroneous heights on the earlier normals, then the positive departures in the Aleutians are quite a coincidence. Or reasoning conversely, since reliable data of the recent 12-year period in the Aleutian area indicate

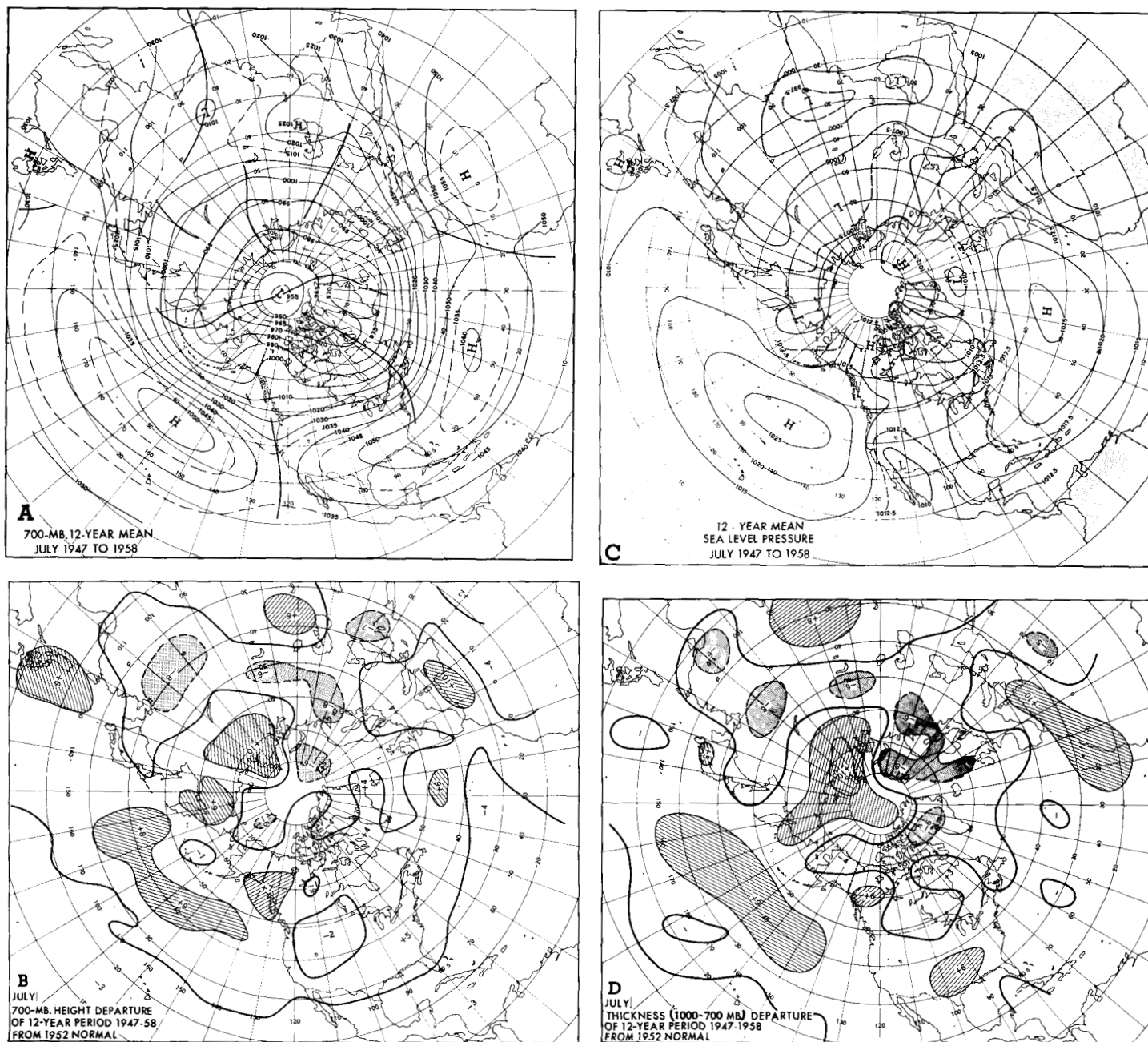


FIGURE 7.—(See legend to fig. 1.)

a trend toward greater heights than in earlier normals, this trend can be confidently attributed to an error in the 1952 normals *only* in the absence of a negative trend of the height differences upstream.

Another area of relatively large height differences at 700 mb. is in eastern Canada and Baffin Bay, from November to June, with a maximum of 250 ft. in February. That these differences are at least partially a manifestation of increased blocking in recent years is suggested by the fact that in some months e.g., December and January, strong negative differences are found immediately to the east, over Europe. Similar patterns were found by Martin [10] in seasonal averages, for the 5-year period 1947-1951, of interrelated 5-day mean height anomalies at 700 mb.

Negative departures from the 1952 normals are greatest in the colder months from the eastern Atlantic across Europe and eastward to Asia at middle and high latitudes. Strong negative differences still exist over Siberia and to a lesser extent over the eastern Atlantic in spring. In the summer and fall months, the negative differences are greatest over the North Atlantic and northern Europe.

A striking alternation from a large negative to a positive difference occurs between January and February near northern Scandinavia and Novaya Zemlya, and to a lesser extent continues through March and April. The 270-ft. positive difference in February over Novaya Zemlya is the greatest difference from the earlier normals observed

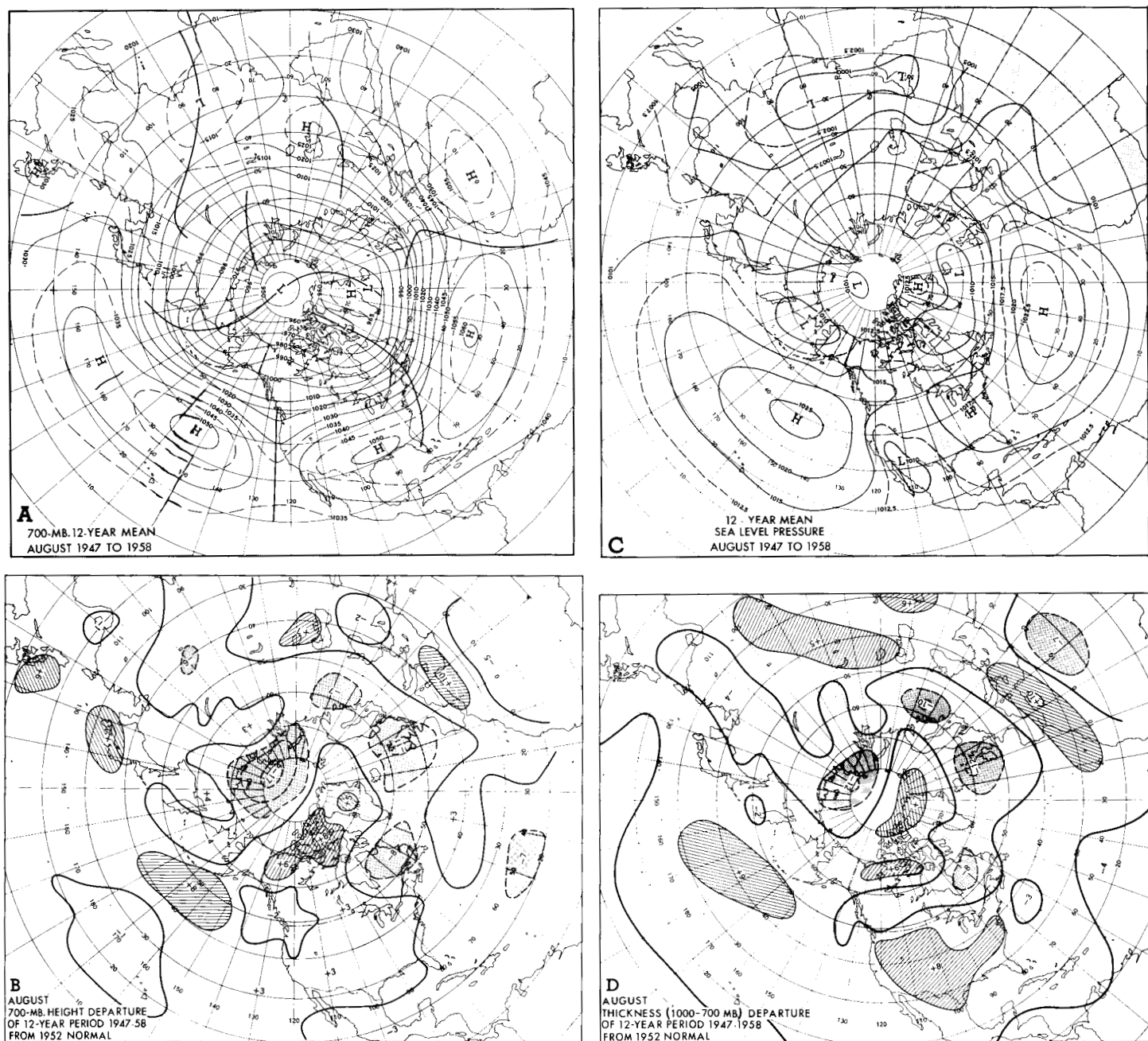


FIGURE 8.—(See legend to fig. 1.)

at 700 mb. This may reflect either an increased blocking trend or a correction of errors of analyses in earlier years.

October (fig. 10B) is also an unusual month in the sense that negative differences appear in the 12-year means throughout the higher latitudes. This implies stronger westerlies in the polar latitudes during October than in the earlier normals.

On a hemispheric basis the positive height departures exhibit a northward migratory trend, primarily in the western sector of the hemisphere, from about December to May, after which they recede southward to middle latitudes in the last half of the year. The negative departures, on the other hand, dominate the high latitudes

from late summer to October, after which they recede southward, primarily into the eastern sector. The net effect of these height differences on the westerlies in the western sector of the hemisphere is shown in figure 13.

7. DIFFERENCES IN THE 700-MB. ZONAL INDICES

Figure 13 gives a comparison of the annual variation of zonal indices at 700 mb. for the western sector of the Northern Hemisphere, between the new 12-year means and the 1952 normals. Overall, the 1947-1958 average westerlies are slower than those in the normals, with the polar westerlies averaging 0.26 m.p.s. less, and the subtropical westerlies 0.75 m.p.s. less.

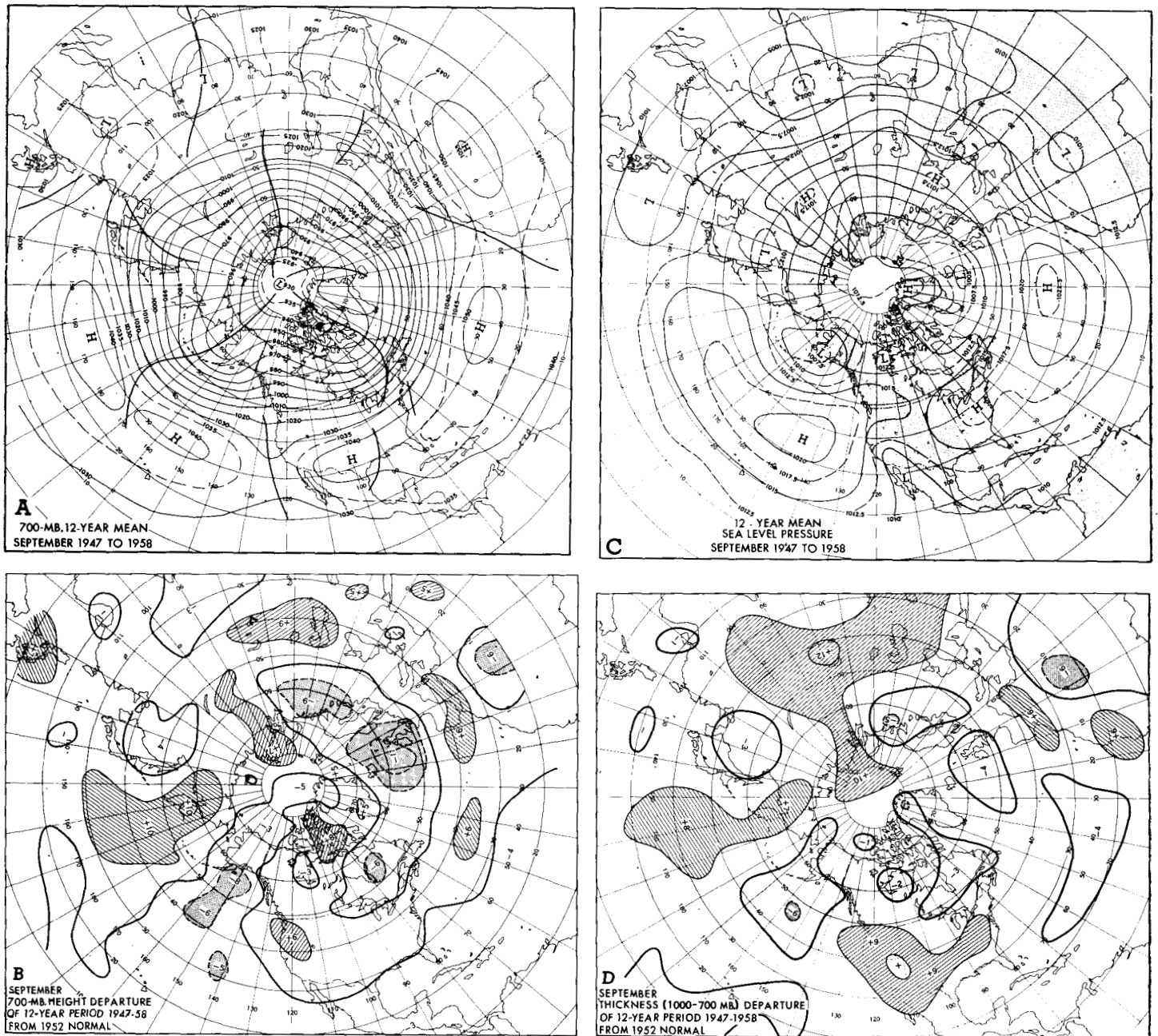


FIGURE 9.—(See legend to fig. 1.)

The subtropical westerlies at 700 mb. are slower in all months in the 12-year means, with the minimum speeds occurring in July instead of in August. At mid-latitudes, the westerlies are stronger in the 1947-1958 means than in the normals in summer and fall and weaker in winter, with the annual maximum in December instead of in January, and a single minimum in July instead of a double minimum in June and August. In the polar latitudes, the westerlies reach a sharp maximum in October on the 12-year means.

8. STABILITY OF THE 700-MB. HEIGHT DIFFERENCES

One criterion of the reliability of a new set of long-period averages is the relative stability of the differences

between the new means and the earlier ones. Ideally this would require two new sets of consecutive averages and a sufficiently long sample of new data to justify this procedure. Since such a new sample was not available, it was decided to compare the departures of the new 12-year means (1947-1958) with the departures of a set of 8-year means (for the years 1946-1953) which had previously been prepared in the Extended Forecast Section. Maps at high latitudes for the period 1948-1955 were published by Namias [4] for the months of January, April, July, and November. A mean of 8 Mays from 1946 to 1953 was published by Klein [11] in 1954 (see his fig. 9). Figure 14 shows the departures from the 1952 normals of 8-year means at 700 mb. for the period 1946-1953 for

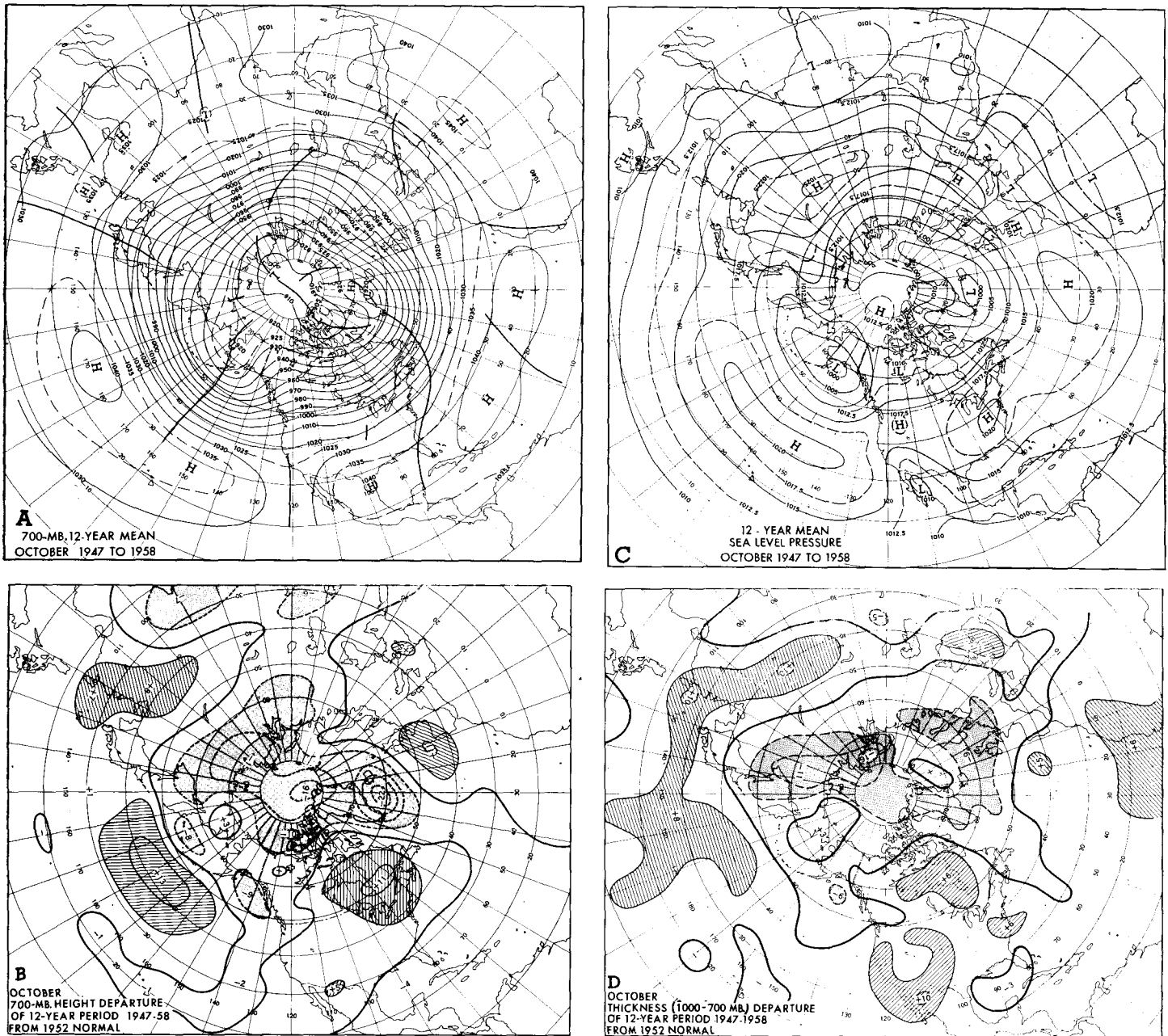


FIGURE 10.—(See legend to fig. 1.)

three additional selected months, February, June, and October. These may be compared with the differences from the 1952 normals of the 12-year means in figures 2B, 6B, and 10B, respectively.

The similarity of the departures of the 8-year and 12-year means for these months is equally strong for the other months (not shown). In general the patterns show considerable stability and, with few exceptions, the differences between the departures of the 8-year and 12-year means, where they exist, are generally in a direction away from the earlier normals.

In February, for instance, the departures almost without exception, are greater in the 12-year average than in the 8-year average. In June the majority of the departure centers have intensified with time, except for some in the

western sector of the hemisphere. In October, the departure patterns show greater stability, but the trend if any, is still that of increased differences from the earlier normals with the larger sample of new data. A very stable departure pattern is observed in the region of northeastern United States and southeastern Canada, where the +110-ft. departure remains unchanged.

There appears to be little doubt that the large differences between the departures of progressively longer-period averages, which are observed in some areas such as Baffin Island, Scandinavia, and the Bering Sea, reflect, in addition to compensation for earlier errors, important secular trends in the average circulation from that represented by the earlier normals. The more stable differences in other areas are more likely to reflect the locations of

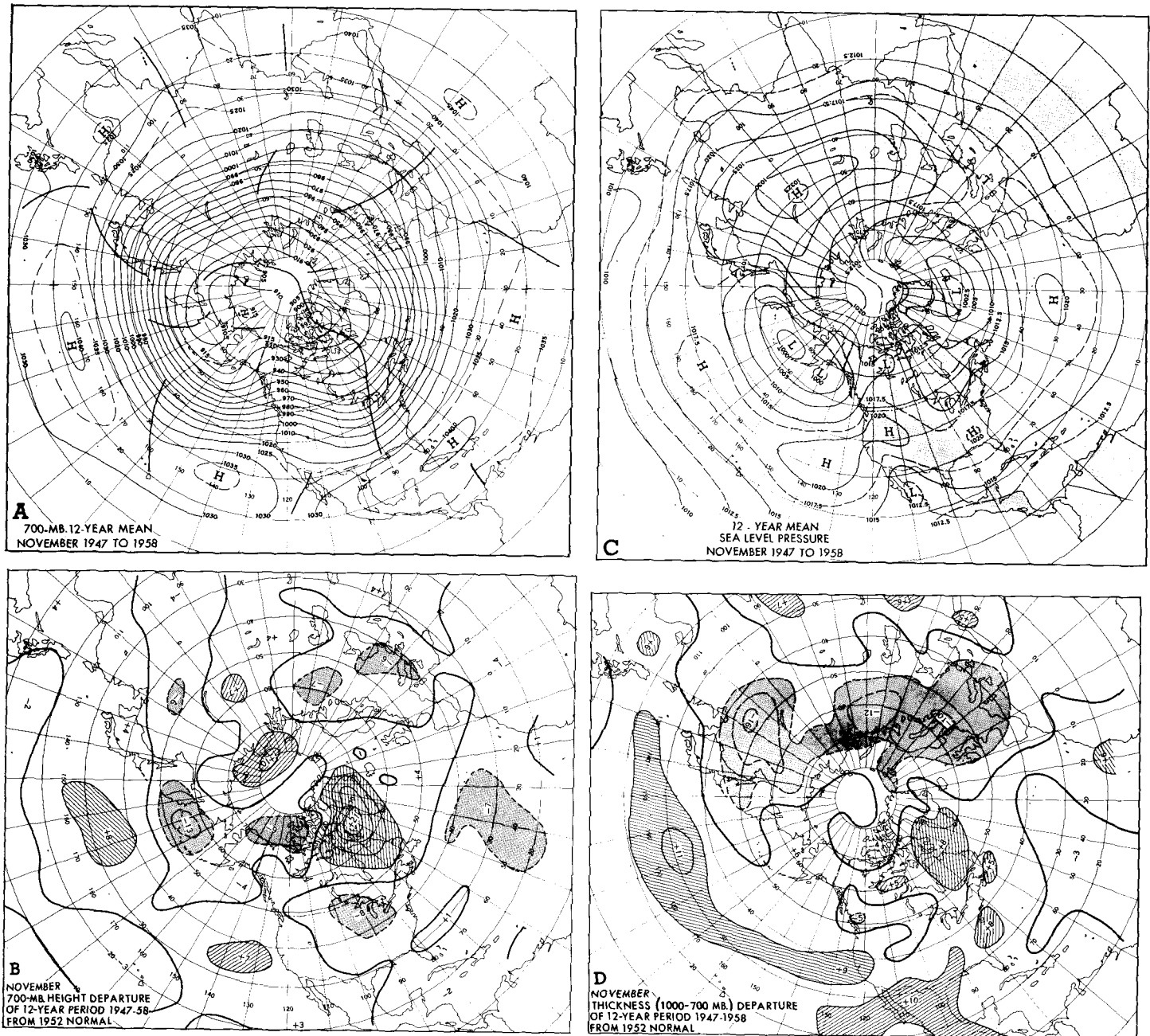


FIGURE 11 —(See legend to fig. 1.)

errors in the earlier normals. In the few areas where the trend of the departures is back toward the 1952 normals, the departures of the 8-year means probably represent an overcorrection of earlier errors, and also in part a cyclical trend of a more temporal nature.

9. COMPARISON OF SEA LEVEL PATTERNS

Figures 10C to 12C portray the 12-year averages for the years 1947–1958 at sea level. Some of the noticeable differences from the 1952 normals are pointed out below. There are many additional differences, of course, and these generally correspond to those previously observed at 700 mb.

Systems which appear on the 12-year means but not on the normals are:

- (a) Secondary Lows appear in the Gulf of Alaska in January and February.
- (b) A Low is found in the Adriatic and the ridge connects across Europe in April.
- (c) There is a Low over Quebec in May.
- (d) In June a closed Low appears southwest of Iceland.
- (e) A weak High is found over the Philippines in July.
- (f) In September an inverted trough makes its appearance over Hatteras.
- (g) A separate Low forms in the Bering Sea in November.

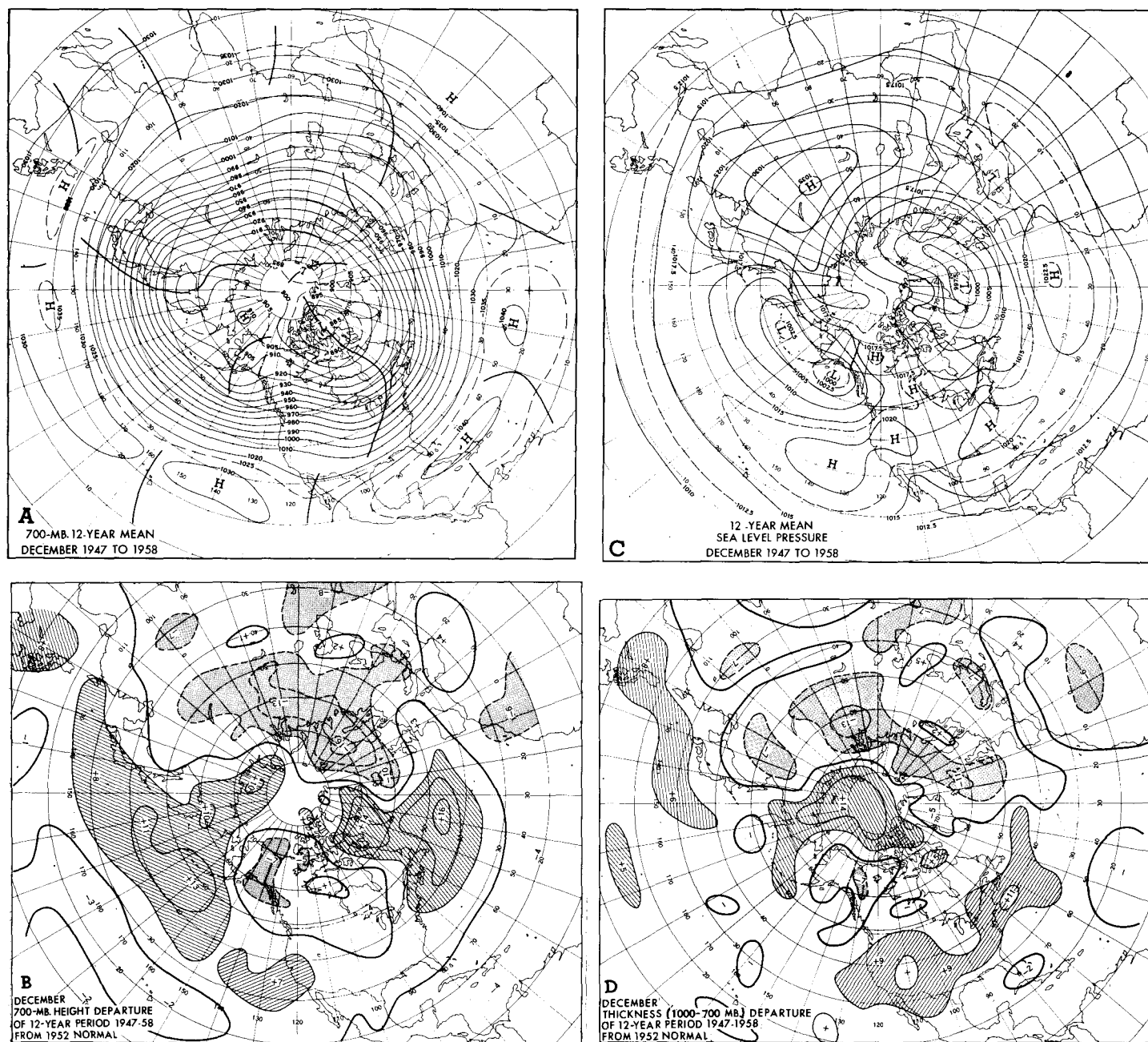


FIGURE 12.—(See legend to fig. 1.)

Systems which appear in the normals but are not found in the 12-year means are:

- (a) Highs show up in the Arctic in January, July, and August.
- (b) In July there is a Low over southern China.
- (c) A Low appears in Davis Strait in November.
- (d) The Colorado Low appears in December and January.

Some other features of the 12-year means which differ from the 1952 normals are:

- (a) The Yukon High has an unbroken connection with the southeastern United States High, and in February the latter is disconnected from the Atlantic High.

- (b) In April the main Low center is in the Bering Sea instead of near Kodiak.
- (c) In May the Indian Low is deeper and farther south-east, while the Bering Sea Low is farther west.
- (d) In June the Indian Low is much farther southeast and deeper on the 12-year mean.
- (e) In July a stronger ridge extends from the Mediterranean over North Africa, forcing the Sahara Low west to near 0° longitude.
- (f) In August a Low appears near the North Pole in the area of high pressure shown in the earlier normals.
- (g) In September, the deepest Low is centered near Iceland instead of over Davis Strait, and in the

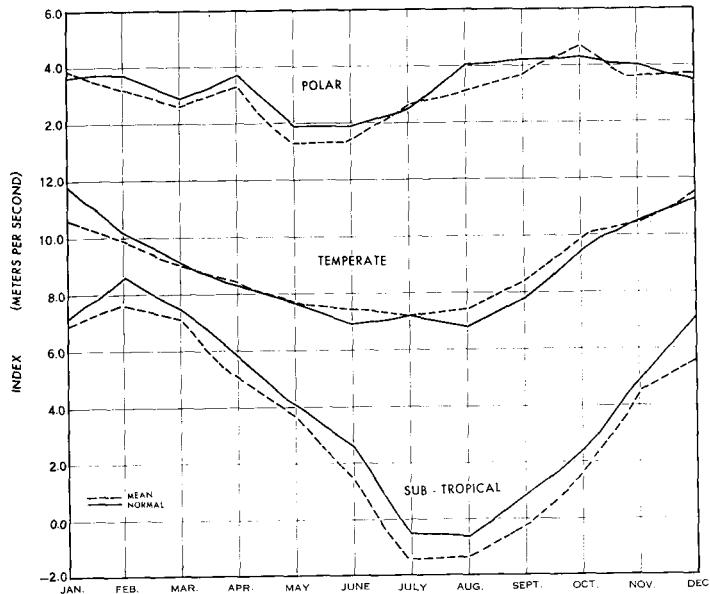


FIGURE 13.—Annual variation of 12-year average monthly 700-mb. indices (dashed) in meters per second for the western sector of the Northern Hemisphere (0–180° W.). Subtropical index applies between latitudes 20° N. and 35° N., temperate between 35° N. and 55° N., and polar between 55° N. and 70° N. “Normal” indices (solid) are averaged from maps in [1].

Pacific a low center exists east of the Philippines instead of over the South China Sea.

- (h) In October a single deep center occurs near Iceland instead of weaker double centers in the normal.
- (i) In December the Azores High is about 5° farther north, while in the Pacific, the deepest Low is near Kodiak instead of the Bering Sea.

The patterns of monthly pressure differences between the 1947–1958 sea level means and the normals (not shown) correspond fairly closely to the height differences at 700 mb. shown in figures 1B to 12B, especially for the major centers. One of the areas in which persistent differences from the earlier normals show up is in the vicinity of the North Pole where pressures on the 12-year means are lower than in the normals in all months, except May, to varying degrees from 1 to 4 millibars. The largest departures occur in July and August and again in December. The differences are not as great in July as suggested by Reed and Kunkel [6]; the patterns conform more nearly to the 8-year average published by Namias [4].

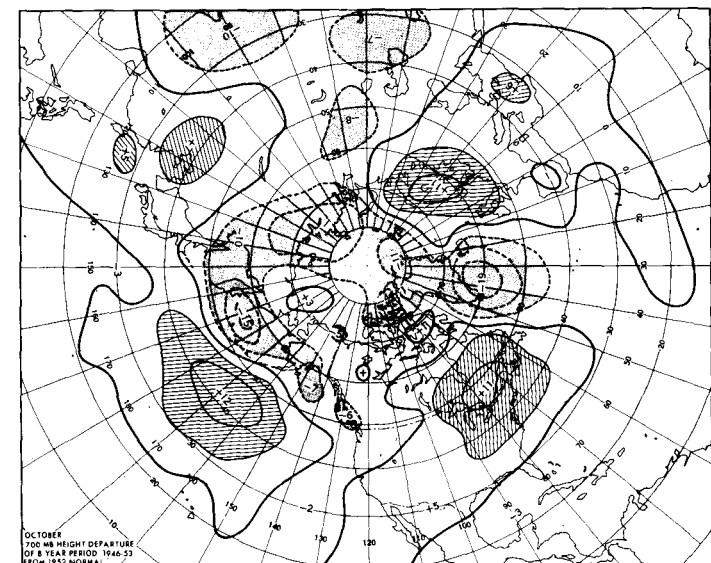
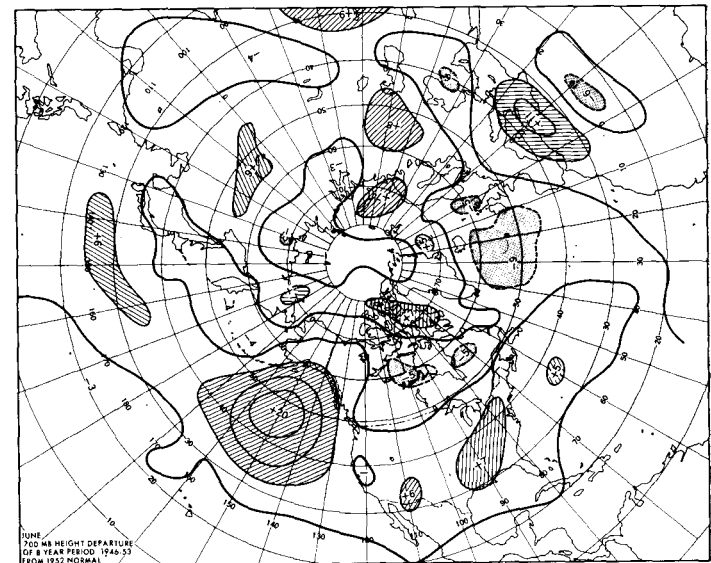
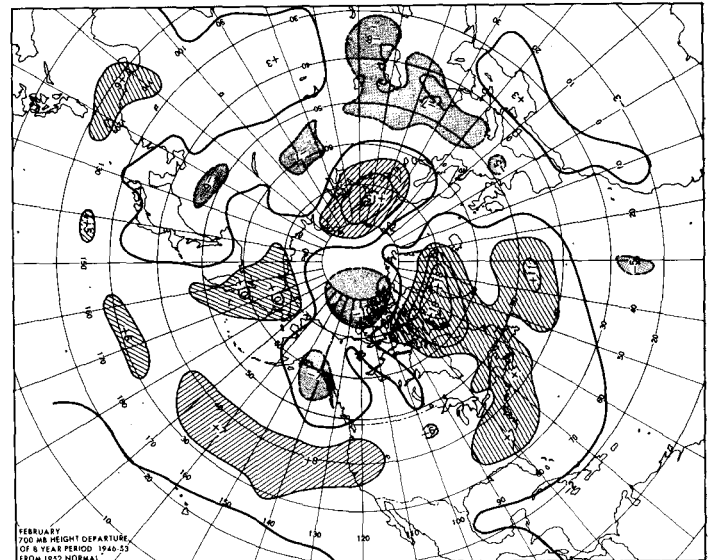


FIGURE 14.—Height differences (tens of feet) between 8-year average 700-mb. heights and corresponding 1952 normals [1]. Heavy solid lines indicate zero differences. Hatched areas have positive differences and stippled areas have negative differences of more than 50 ft. The lines are drawn at intervals of 50 ft. with positive differences solid and negative differences dashed.

In other areas there are displacements of the sea level departure centers from the corresponding 700-mb. centers. For example, a negative sea level departure center in January in the Sea of Okhotsk (not shown) is probably related to the negative 700-mb. center (fig. 1B) over Manchuria. This implies that thicknesses were greater in the 1947–1958 period over Kamchatka and less over Siberia than in the earlier normal.

An overall integration of the local differences between the sea level pressure departures and the 700-mb. height departures of the 1947–1958 means from the 1952 normals is probably best portrayed by the monthly 1000–700-mb. thickness departures (figs. 1D–12D). In addition, the patterns of monthly thickness departures show how the mean virtual temperature regime of the years 1947–1958 compares with the earlier period embraced by the 1952 normals.

10. COMPARISON OF THICKNESS PATTERNS

Figures 1D to 12D show the monthly departures of the 1947–1958 average thicknesses between 1000 and 700 mb. from the 1952 normals. Some of the departures may be due to the fact that the method used to reduce sea level pressure to height of the 1000-mb. surface differs in the two cases. (See section 3 above and page 4 of [1].)

From October to April the European and Asiatic sectors of the hemisphere, especially at higher latitudes, show decreased thicknesses from the 1952 normals, the largest departure (200 ft.) appearing in April near the Laptev Sea. This is equivalent to about a 10° F. decrease in virtual temperature. During the remainder of the year, thickness differences over Asia and Europe are smaller and more variable.

Over the North American area, thicknesses appear generally greater in practically all months except in western Canada from November to June. The largest decrease and associated cooling occur in February with a 140-ft. center over Alaska and the Yukon. Increasing thicknesses of about 100 feet occur in a number of months over the southeastern United States, the Northeast, and the Maritime Provinces.

In the North Atlantic, thickness differences are generally small, except in the extreme northeastern part, where thicknesses near the United Kingdom decrease in practically all months, sometimes 100 feet or more.

In the Pacific, thickness differences are generally positive especially from June to November.

11. CONCLUSIONS

The 1947–1958 means at 700 mb. are based upon actual data that are superior to the data used in the 1952 normals. Significant differences from the earlier period as well as additional information come to light. Some of the differences appear to reflect compensation for errors in the earlier normals, while others seem to be more clearly linked to secular changes. The latter are manifested

in couplets of contiguous positive and negative differences, which are dynamically compatible.

The new 12-year means more accurately reflect current modes of synoptic behavior, as shown in a separate study of the frequencies of 5-day mean Highs and Lows. When three more years of data, 1959–1961 have been added, it is planned to supplant the 1952 normals with a new set of long-period (15-year) means. This new set will be based on essentially hemisphere-wide post World War II upper-air data coverage and should more accurately reflect the long-period circulation.

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